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INJURIES AMONG MILITARY PARATROOPERS—CURRENT EVIDENCE AND DATA GAPS

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PURPOSE. The purpose of this effort was to synthesize the body of evidence regarding military paratrooper injuries in order to: (1) characterize injury rates, types of injuries, and risk factors and (2) describe inconsistencies, data gaps, and hypotheses for future study.

REFERENCE(S). Appendix A lists references cited within this document.

POINTS OF MAJOR INTEREST AND FACTS.

Military Paratrooper Populations.

General.

Military paratroopers are active military personnel who are required to jump out of aircraft (planes, helicopters, balloons) as part of their assigned military duties (Bricknell 1999, Knapik 2003). In both U.S. and international militaries, paratroopers are assigned to a variety of units (e.g., occupational groups) with diverse missions. Examples include combat and infantry, Special Forces, rescue and firefighting, and aerial demonstration teams (e.g., U.S. Army Golden Knights). The jump exposures of these units can reflect differences in equipment, training and operational procedures, environmental conditions, and frequency of jumps.

To become a qualified paratrooper, military personnel must successfully complete an initial parachuting training program (Ekeland 1997, Bar- Dayan 1998, Amoroso 1998, Bricknell 1999, Knapik 2003). Depending on the type of paratrooper duties and unit, personnel may also be required to participate in advanced paratrooper training programs. For this review, the term “operational paratrooper” refers to personnel who have met at least the basic qualification and are in active paratrooper status. Those in the process of becoming qualified in the initial training are “paratrooper trainees.”

U.S. military paratroopers and trainees.

The basic paratrooper qualification program for U.S. military Services (Army, Air Force, Navy, Marines, Reserves, and National Guard) is conducted at the Airborne School at Ft. Benning, Georgia. The program (aka Jump School or Paratrooper School) is 3 weeks long and includes a ground week, tower week, and jump week. Graduation requires five successful jumps, including one night jump with a variety of different equipment levels, from virtually nothing to a full combat load. (Amoroso 1998, Knapik 2003, U.S. Army 2018). Though “qualified” as paratroopers, not all U.S. Airborne trainees that graduate go on to be active operational paratroopers. The percentage of graduates that become active operational paratroopers may vary because the Services’ mission needs change year to year. As of 2012, the U.S. military capped the number of paratrooper positions to 49,000 (Barrouquere 2019). Though the majority of these positions are assigned to the Army, the number of active Army paratroopers is not readily known due to changing unit missions and needs (Quora.com 2019).

Because the U.S. military considers parachuting duties exceptionally dangerous or life-threatening, qualified active military paratroopers are provided additional hazard pay known as "Jump Pay," or "Parachute Duty Pay." There are two rates of Jump Pay—regular and High Altitude, Low Opening (HALO). To be qualified, military members must make at least one qualifying jump during a consecutive 3-month period (four jumps a year) to continue to maintain active status (2017, U.S. DoD 2018; USC 2017). For regular jump pay ($150 per month as of 2017), personnel are qualified as a parachutist or parachute rigger (Soldiers who pack the parachutes but who are also required to jump) or are undergoing training for such designations. For HALO ($225 per month), the paratrooper has to have parachute jumping as an essential part of his/her regular duties, in military free fall operations where a static line is not used for the jump. (U.S. DoD 2018; USC 2017, Powers 2019).

Problems with military paratrooper risk characterization.

In general, the literature describes military paratroopers as relatively small components of military populations who have a high risk of injury due to their unique and "inherently dangerous" jump activities (Ekeland 1997, Bricknell 1999, Hays 2006). Physiologically this seems to make sense, since most parachuting injuries occur during the landing when the sudden ground impact is a force described as 10–15 miles per hour and sometimes more (Ekeland 1997, Bricknell 1999, Knapik 2003). Entanglements and parachute failures are less common but can cause serious (even fatal) injuries (Bricknell 1999, Knapik 2003).

However, studies do not consistently characterize the inherent injury risk hazards of military parachuting. For example, Bar-Dayan et al (Bar-Dayan 1998) notes, "Parachuting is regarded as relatively safe." The context of this risk characterization is perhaps better described by Knapik et al (Knapik 2003) who explains, "Military parachuting appears relatively safe if procedures that have been developed over long periods of time are followed," but that "Military airborne operations can still entail some risk of serious injury and death under certain conditions." Problematic is that these statements are not actually comparing parachuting-related injury risk to other military activities. Existing studies regarding military parachuting injuries have only included injuries among populations of operational paratroopers or paratrooper trainees. These studies characterize the risk based on the number of jumps (e.g., the number of injuries per 1000 jumps). These injury risks cannot be compared to those involving other military exposures (i.e., running, foot marching, combative training). In other words, there have been no studies of the injury risk between military cohorts who have no parachuting exposures compared to paratrooper counterparts. Current Army medical surveillance systems have also not compared paratroopers' medical records to those among other military occupations.

The lack of an established military paratrooper medical surveillance program has also been previously noted as a key limitation to comparisons among paratrooper studies (Farrow 1992, Knapik 2003, Hughes 2008). These older studies suggested the use of a medical surveillance program could have standardized the methodological protocols among paratrooper studies including differences in—

- Injury definitions, body region and injury type groupings, and data collection methods.
- Populations and experience (i.e., international or United States; operational, deployed, or trainees).
- Aircraft (i.e., planes/types, balloons, helicopters) and jump type (i.e., free fall, static line).
- Environments (i.e., night versus day, weather and wind, drop zone (DZ) characteristics).
- Equipment (e.g., population with/without combat equipment; use of side versus rear exit, parachute and harness types, protective equipment (i.e., ankle braces, helmet-types)).

Current Evidence Synthesized.

This effort assimilated the published literature relative to six aspects of injury etiology: populations studied, injury definitions, injury rates, body regions injured, risk factors, and interventions. Due to study inconsistencies, data were only semi-quantitatively or qualitatively synthesized. Findings are summarized below -

Data sources and population studied.

A systematic search of literature from 1990 to 2017 in PUBMED, using the terms “parachuting” or “paratrooper” and “injury” and addition of key secondary citations, produced 21 relevant publications. Extracted details of the 18 original studies and three reviews are presented in Appendix B. Table 1 summarizes the populations studied. Eleven of the 18 studies assessed operational units (one deployed), while seven focused on paratrooper trainees. Twelve of the 18 studies were on U.S. military populations. The data were primarily on populations conducting static line operations, which are most prevalent among military paratroopers. There was very little evidence pertaining to HALO paratroopers.

Injury definitions.

Despite variations in injury definition and data collection, published studies (described in **Appendix B**) have consistently focused on the acute traumatic (ACT) injuries that are the result of a specific “jump” or “descent” (i.e., the timeframe from leaving the aircraft to the landing). The identification of these injuries has primarily been by the observation of medical personnel at or near the DZ at the time of landing. A few studies allowed a “risk period” of a few days or weeks after a jump identified in medical records (Kragh et al 1996, Schmidt et al 2005).

Most studies defined injuries as casualties requiring immediate medical evaluation, which explicitly or implicitly included conditions preventing further jumps and/or that resulted in some level of restriction of physical activity. Examples include injuries specified as conditions that needed urgent medical care and/or required evacuation from the DZ for treatment or a condition requiring varying days of physical restriction or sick leave. While most studies did not distinguish levels of injury severity, some studies characterized emergency department (ED) or evacuated and hospitalized (inpatient) injuries as more severe than outpatient injuries (Craig 1997, Hughes 2008). A few studies qualified levels of severity further. Kragh et al. described three levels of injury severity: mild (less than 72 hours restricted activity), moderate (greater than 72 hours restriction), or severe (requiring hospitalization) (Kragh 1996). Bar-Dayan et al. described contusions and sprains as “minor” and fractures or head trauma as “major” (Bar Dayan 1998). Severity of strains and strains were inconsistently characterized as “serious” or “severe” (Craig 1999, Schumacher 2000) or “minor” (Farrow 2992).

Injury rates.

Studies cited the number of injuries per number of jumps as the metric to report paratrooper injury rates. The denominator (number of jumps), is usually quantified as being 100 or 1000, which standardizes the unit of exposure for paratrooper studies. Rates were also sometimes presented as a percentage of number of injuries per jump—for example, an injury rate of 2.2% referred to 22 injuries per 1000 jumps (Kragh 1996).

Though a rate of 6 injuries per 1000 jumps (Bricknell 1999, Knapik 2008) has been noted as a typical military paratrooper injury rate, this injury rate is contradicted by other studies. Specifically, grouping rates separately for operational and trainee population paratroopers suggests potential population differences. For example, injury rates for operational paratroopers are higher than the rates for paratrooper trainee populations (Table 1). When evaluating U.S. military populations separately from international military studies, U.S. paratrooper studies found slightly lower injury rates (Table 1). The lowest rates reported were for U.S. airborne trainees (median = 5.5 per 1000 jumps, average = 6.3 per 1000 jumps). These U.S. Airborne trainee injury rates tended to be 50% less than those for U.S. operational paratroopers (median = 13 per 1000 jumps, average = 15 per 1000 jumps).

Some studies characterized parachuting injury rates as ranges to account for the varying conditions (Table 2). This has also demonstrated the problem with citing 6 injuries per 1000 jumps as a typical injury rate. For example, Bricknell et al. (Bricknell 1999) describes a range of 0.9 to 22 injuries/1000 jumps for all scenarios, including jumps from balloons (which represent the lowest end of the range). Ekeland et al (Ekeland 1997) described 11 injuries per 1000 jumps as “relatively low compared to other reports of 3 to 24 injuries/1000 jumps.” In a 1998 review, Bar-Dayan et al (Bar-Dyan 1998) described 9 injuries per 1000 jumps and the range of 3 to 14 injuries per 1000 jumps (0.3 to 1.4%) as “relatively low.” To more explicitly acknowledge the impact of diverse conditions, Craig et al (Craig 1997) advised planners to expect “10 acute trauma injuries per 1000 jumps, with a variation of 50% (i.e., 5 to 15 injuries per 1000 jumps) depending on wind, weather, and experience.” Craig et al. later found a rate of 22 per 1000 (United States) versus 29 per 1000 (United Kingdom) in a mass tactical assault training scenario conducted with combat gear at night in inclement scenario (Craig 1999).

Body regions injured.

In addition to different inconsistent definitions of injury, studies have often described the location of injuries in different ways. For purposes of this review, specific anatomical locations of injuries were broadly grouped into six general body regions: (1) head and neck, (2) spine and back,

(3) torso and abdomen, (4) upper extremities,(5) lower extremities, and (6) multiple sites or systems (APHC 2017). Due to inconsistent body region and anatomical classifications in the literature, this evidence is summarized qualitatively.

Lower extremities.

The lower extremities included the hip, upper leg, knee, lower leg, ankle, foot and toes. The findings of this review reflect studies conducted long after worldwide implementation of the parachute landing fall (PLF) in the 1940s (Bricknell 1999; Knapik 2003, Knapik 2011a). Though the literature search did not provide data that quantified the rate of injury reduction attributed to the PLF, the literature describes the PLF as substantially reducing ankle injuries by distributing landing force through a sideways landing. The PLF continues to be doctrinally taught to U.S as well as international military paratroopers (Bricknell 1999, Knapik 2003).

Despite the mandated PLF use, previous reviews indicate the lower extremities (in particular the ankle) are still the primary body region injured during parachuting (Bricknell 1999, Knapik 2008). Other common lower extremity injuries have included fractures in the foot and lip of tibia (from feet and toes pointing on landing), knee ligament tears, fracture of fibula, and sprain of tibio-fibular joint (Bricknell 1999, Appendix C Table C-1).

Based on this review, the evidence indicates the lower extremity body region is the most commonly reported among studies (Table 1, and Appendix B). The most frequently reported anatomical site was the ankle, for which most reported injuries were sprains. Fractures to the ankle were less frequent. Ankle injuries were more consistently described in the studies of trainee populations followed by fractures (Brickell 1999, Ekeland 1997, Amoroso 1998, Schumacher 2000, Knapik 2003, Knapik 2008). Among the operational population studies, the leading location of injuries reported were more varied (Table1).

Head and neck, and *back and spine.*

Head and neck injuries included closed head trauma (e.g., concussions, traumatic brain injury (TBI)); open wounds to head, face, eye, and ear; fractures in neck, and soft tissue damage (contusions as well as sprains or strains). Back injuries include strains, sprains, and compression fractures that are attributed to the landing force transmitted through the coccyx up through the spine (Ekeland 1997, Craig 1997, Hays 2006, Knapik 2008, Knapik 2014). Some operational paratrooper studies even suggest these head or spine body regions may be more frequently injured than the lower extremities (Farrow 1992, Hays 2006, Knapik 2011a, Knapik 2014). As an example, recent studies of U.S. operational soldiers identified closed head injuries as the leading injuries (Knapik 2011a, Knapik 2014). Head and neck injuries have been attributed to backward falls on landing or a jarring impact when the head whips back during the PLF forward tuck (Bar-Dayan 1998, Bricknell 1999, Craig 1999, Knapik 2014, and Appendix C Table C-1).

Upper extremities.

Though less commonly reported, several shoulder injuries have been described as classic parachuting injuries: fractures or dislocations of the shoulder, which occur when elbows are not tucked in tightly on landing (Appendix C Table C-1); partial or full dislocations of the acromioclavicular joint, which occur during landing on the point of shoulder, and entrapment with the static line upon exit, which has caused ruptures of the biceps brachii (Bricknell 1999). The shoulder injuries frequently attributed to parachuting have been described as particular “severe” injuries (Farrow 1992). The high frequency of shoulder injuries identified in three operational Australian studies suggests this anatomical site may be a problem among certain paratrooper populations. The risks may be associated with specific equipment or protocols (Farrow 1992, Hays 2006, Hughes 2008). The U.S. studies have not identified upper extremities or shoulder to be leading injuries in magnitude (incidence rates).

Table 1. Military Paratrooper Injuries Reported in Identified Studies (Appendix B)

Source			Injuries/1000 jumps	Injury definition	Leading injuries
OPERATIONAL	UK	Lillywhite (1991)	14 night; most w equipment 11 day; most w equipment	"during parachuting and attended to by medical party in the DZ"	--
	AUS	Farrow (1992)	[*07 overall*] 03 no equipment 14 with equipment 17 equipment, simultaneous doors	"recorded only if severe enough to require evacuation from DZ" Included minor, moderate, severe(fx)	Shoulder *(severe)*-11% Ankle (*minor*)- 11%
	US	Kragh (1996)	[*22 overall*] 13 (day, field) 51 (night, landing strip)	"acute anatomic lesion producing duty restriction": Mild<72 hours (hrs), Moderate= >72 hrs, Severe= >24 hrs complete work loss (hospitalized)	Lower extremity - 57% *(ankle, knee, foot)* Back/spine -15%
	US	Craig (1997)	[*08 overall*] 05 monthly low end rate 13 monthly high end rate	"determined by ER staff to have occurred during airborne operation"	Lower extremity- 27% Back/neck - 19% Head (closed) -18%
	US	Craig (1999)	22 (US, equipment, tactical, night)	" from [aircraft exit] to drop zone "	Lower extremity - 38% Back - 16% Head (closed)-10%
	US	Schumacher (2000)	17 without ankle brace 13 with ankle brace	'duty limiting injury per sick call or ER visit'	Lower Extremity >75% *(ankle 27%, knee 20%)* Back - 21%
	AUS	Hay, ST (2006)	[*15 overall*] 10 no equipment 11 with equipment 33 tactical with equipment	'recorded only id severe enough to require evacuation from the DZ'	Back -29% Shoulder -19% Head/neck - 10%
	AUS	Hughes (2008)	51 [26 severe only]	Less severe result in minor restriction and more severe injury required hospitalization	Back - 75% Shoulder – 25%
	US	Deaton (2010)	08 [8.2; 2.1*] maneuverable	(Deployed) presented to military surgeon related to airborne operation regardless of duty status"; *Major injury=evacuation	Lower extremity - 62% *(upper leg/knee - 50%)* Head/neck - 37%
	US	Knapik (2011a)	11 (T10, multiple operational conditions to evaluate risk factors)	field medical determination	Head (closed) - 34% Lower extremity - 24% *(ankle 18%, knee 6%)* Back - 11%
	US	Knapik (2014)	08 (5.5 T-11 vs 9.1 T-10)[e]	"any …damage to body, seen by medic/ PA in DZ...aircraft to harness removal"	Closed head 29-38% Lower extremity>20%
	All Operational		Range = 3.3 to 51 (3, 5, 8, 8, 11, 11, 13, 13, 13, 14, 14, 15, 17, 17, 22, 51, 51) Median = **13** Mean = **17 injuries/1000 jumps**		
	US Operational		Range = 5.0 to 51 (5, 8, 8, 11, 13, 13, 13, 17, 22, 51]) Median = **13** Mean = **15 injuries/1000 jumps**		
TRAINEES	NOR	Ekeland (1997)	20 basic course (19.7) 05 post basic training (4.5)	'sought medical consult for, whether or not sick leave or seen several days after injury'	Lower extremity - 80% *(ankle 36%)* Spine, 11%
	US	Amoroso (1998)	11 single, mass, night equipment	any MSK or traumatic condition occurring from aircraft exit to DZ march off that results in inability to clear DZ; ER visit, Dx at clinic"	Ankle - 80%
	ISR	Bar-Dayan (1998)	09 (8.9)	"that prevented further jumps for at least 2 days after injury"; Minor = contusion, sprain; Major = fracture, dislocation, head trauma	Ankle >30% (vs non) Minor injuries - 68%
	US	Schmidt (2005)	--	Acute traumatic injuries per medical records review of ICD codes and parachuting external cause code ; 5 week risk period	Ankle - 63% (vs non)
	US	Knapik (2008)	06 [5.8; 5.2 brace, 6.1 no brace]	field medical determination	Ankle - 37% Head - 17% Sprain 33% vs Fx 25%
	US	Luippold (2010)	--	ICD9 codes: acute trauma, others	Ankle - - 29%
	US	Knapik (2011b)	03 (2.5) daytime, non-tactical	consultation with medic in field	Ankle 20-32% Head 13-15%
	All Trainees		Range = 3 to 20 (3, 5, 6, 9, 11, 20) Median = **8** Mean = **11 injuries/1000 jumps**		
	US Trainees		Range = 3 to 11 (3, 5, 6, 11) Median = **5.5** Mean = **6.3 injuries/1000 jumps**		

Table 2. Example Parachuting Injury Rate Ranges

Source	Average a		Range [a]		Other metric:
	injuries/ 1000 jumps	% of 100 jumps	injuries/ 1000 jumps	% of 100 jumps	injuries/ 100 soldiers
Lillywhite 1991	15	1.5	0.6 – 8	0.06 – 0.8	
Craig 1997	10	1.0	5 – 15	0.5 – 1.5	4.7 (5.8 <30 years, 2.7 >30 yr)
Ekeland 1997	11	1.1	3 – 24	0.3 – 2.4	
Bar Dylan 1998	9	0.9	3 – 14	0.3 – 1.4	
Craig 1999 [b]	22	2.5	22 – 29	2.2 – 2.9	
Bricknell1999 [c,d,e]	6	0.6	0.9 – 22	0.09 – 2.2	
Deaton 2010	8	0.8	3 – 24	0.3 – 2.4	

Notes:
[a] Values rounded and represent diverse scenarios; see Appendix B for source details.
[b] lower end of range attributed to U.S. paratrooper versus 29 for United Kingdon in a mass tactical assault training exercise, with combat gear, at night and in inclement weather.
[c] Range includes jumps balloon jumps (lowest end of range).
[d] Averages for specific scenarios: 1.8 injuries/1000 daytime jumps from plane no equipment; 8.5 injuries/1000 daytime jumps from plane with combat equipment; and 10 injuries/1000 nighttime jumps from a plane with combat equipment.
[e] This average (6 injuries/1000 jumps) cited evidence of injury reduction compared to 1940's rates of 21 to 24 injuries/1000 jumps (Knapik 2003, Knapik 2008)

Exposure scenarios and risk factors.

The ranges of military parachuting related injury rates cited in the literature demonstrate the impact of certain other external risk factors. The primary focus of past study has been static line jumps from aircraft such as planes because: (1) parachuting from planes incurs a higher risk of injury than from balloons or helicopters, and (2) static line jumps from planes are the most common military jump (Bricknell 1999, Knapik 2008). Though different planes are described, the C-130 fixed wing is the most commonly cited in the literature; other examples include C-141, C-17, and C-7 (older) (Lillywhite 1991, Bricknell 1999, Schumacher 2000, Hughes 2008, Knapik 2008, Knapik 2011a).

Though not a comprehensive list of all potential factors, primary factors that have been attributed to increasing the risk of parachuting injuries in the literature are summarized in Table 3. The evidence has consistently and strongly demonstrated that night time/low-visibility conditions and wearing/carrying combat equipment are major contributors to injury risk. The evidence also indicates injury risk can be increased by high wind speeds (e.g. >10 knots), rough terrain or paved landing DZ areas, and the mass simultaneous exit of Soldiers from the side doors of a plane. Injury rates can be predicted to be higher when multiple risk factors are present. Unfortunately, these risk factors are inherent conditions in operational missions and, thus, may be imitated or accepted in many tactical training exercises (DA 2018).

Though less clearly defined, an improper landing technique appears to be the most common risk factor (or cause) attributed to injuries (Ekeland 1997, Bricknell 1999, Hughes 2008, Knapik 2011a). An improper landing is when a Soldiers has not used the PLF procedure. The reasons for not using the PLF are not clear but may be multifaceted due to the confounding of other factors such as environmental condition (e.g., night/low visibility, terrain) and/or personal characteristics or behaviors (e.g., age, experience level, fatigue, failure to remember procedure), and/or lack of oversight leadership to enforcement.

Interventions.

- As previously noted, the literature indicates that the PLF was procedurally implemented by militaries worldwide to reduce the risk of ankle injuries in the 1940s. Some studies describe the previous tremendous risk reduction provided by the PLF, but no quantification of the reduction were described in this review of publications since 1990. Given the continued high risk attributed to improper landing cited in more recent literature, a review of the PLF use and enforcement especially in operational units may be of value. It is noted that the U.S. Army has recently updated its procedural manual for static line jumps, which includes descriptions of various versions of the PLF as well as refresher training requirements for operational personnel (DA Army 2018). Aside from the PLF procedural injury intervention, the evidence included data on two equipment items shown to effectively reduce parachuting-related injury rates -

- Several studies in the 1990s investigated the effectiveness of the outside-of-the-boot parachute ankle brace (PAB) (Amoroso 1998, Schumacher 2000, Schmidt 2005, Knapik 2008, Knapik 2010, Luippold 2011). Repeated findings demonstrated that the PAB was effective and significantly reduced overall injury rates, which included a 40% to 50% reduction in ankle injuries. Despite the effectiveness and an estimated cost savings between one to three million dollars annually associated with its use, the PAB has never been adopted for official use by U.S. Airborne Corps (DA 2018). The reasons were described anecdotally as discomfort, belief the PAB increased risk of non-ankle injuries, and impracticality during exercises and missions (Knapik 2010, Luippold 2011). The literature does not indicate that any international military paratrooper unit or program uses the PAB.

- The U.S. Army's implementation of a new non-steerable parachute design (T-11, square design) was the subject of two studies (Knapik 2011b, Knapik 2014). These studies supported indications that the new design was somewhat safer (Knapik et al reported a "40% lower injury incidence with the T-11) than the previous design (T-10). The hypothesis for the reduced injury rate is that the T-11 descends at a slower rate (18 feet per second, or approximately 12 miles per hour (mph)) than the T-10 parachute (21 feet per second, approximately 14 mph). As of Fiscal Year (FY) 2015, the implementation of the T-11 replacement over T-10 was to have been completed. The two studies (one of a trainee population and one of an operational population) supported the finding of this review that trainees experience ankle injuries more than their operational counterparts who experience more head/neck injuries. Though overall injury rates appeared to be reduced by the T-11, both studies showed a doubling of the percentage of shoulder injuries (Knapik 2011b, Knapik 2014). Though less common than lower extremity and head/neck or back injuries, prior studies have suggested that parachuting shoulder injuries tend to be more severe than lower extremity injuries (Farrows 1992, Hays 2008).

Table 3. Risk Factors that Increase Risk of Parachuting Injuries

Risk Factors	Specific scenario or condition	Impact indicated by evidence*	
Improper technique [a]	Improper parachute landing fall (PLF)[a] cause of "71-87% of injuries" (Ekeland 1997)	High	Farrow (1992) Ekeland (1997) Deaton (2010) Knapik (2011a)
Time of day [b]	Night time, low light[b]	High	Lillywhite (1991) Farrow (1992) Kragh (1996) Ekeland (1997) Bar-Dayan (1998) Bricknell (1999) Knapik (2003) Deaton (2010) Knapik (2014)
Weight carried[c]	Combat equipment[c]	High	Lillywhite (1991) Farrow (1992) Bricknell (1999) Knapik (2003) Hay (2006) Deaton (2010) Knapik (2014)
Lack of protective equipment - parachute ankle brace (PAB)	Not wearing PAB Evidence suggest injury reduction of 15% to 75% of parachuting injuries (ankle injuries being highest); evidence does not indicate PAB increases risk injuries to other body regions (Schmidt 2005 Knapik 2010, Luippold 2011)	High	Amoroso (1998) Schumacher (2000) Schmidt (2005) Knapik (2008) Luippold (2011) Knapik (2010)
Speed of descent (parachute design/type)	Faster descent (T-10, 21 feet per second, which is 14 mph) versus slower descent (T11, 18 feet per second, 12 mph)	Medium-High	Farrow (1992) Deaton (2010) Knapik (2011b) Knapik (2014)
Wind speed	Wind greater than 10 - 15 knots[d]	Medium	Bricknell (1999) Knapik (2003) Deaton (2010)
Landing (DZ) Terrain	Hard (airstrip/airport) or uneven (field)	Medium	Bricknell (1999) Knapik (2003) Deaton (2010)
Exit from plane	Side doors, simultaneous exit Higher numbers of people exiting	Medium-Limited	Bricknell (1999) Knapik (2003) Deaton (2010)

Notes:
* Qualitative descriptor of "impact shown by evidence" based on investigators' assessment of literature.
[a] May be associated with other factors: time of day (low visibility), combat gear, uneven landing terrain. Inexperience (represented as number of jumps, training, age) also suggested but evidence is inconsistent (Craig 1997, Ekeland 1997, Deaton 2010).
[b] Night time and low light scenarios are necessary for many tactical operations (i.e., insertion into the battlefield).
[c] Different combat equipment weigh different amounts – dose response as increases to weight corresponds to increases injury risk.
[d] Less than 5 knots also appears may also increase risk; actual speed that increases risk cited as >9 up through >15.

Conclusions.

General.

Conceptually, the "inherent risks" of military parachuting make physiological sense—but some of the literature describes the activity as relatively safe given the oversight and procedures implemented over the years Despite several limitations, the evidence supports the assumption that U.S. Airborne procedures and training are good at reducing common acute injury risks attributed to parachuting. This is suggested by the lower injury rates among U.S. paratroopers, both those in operational and in training settings. It is also hypothesized that despite high jump exposure, basic Airborne trainees have the lowest injury rates (average 6 acute injuries/1000 jumps) due to the emphasis on safety and instructional oversight. A higher rate of injury among U.S. operational paratroopers (average 15 acute injuries/1000 jumps) may be attributed to unavoidable risk factors but may at least in part be due to less oversight or recall of safety procedures such as proper PLF.

These parachuting-related injury risk rates cannot be compared to the injury risk rates of other military activities and missions. They are also not reflective of the scientifically proven risk reduction offered by the PAB as this intervention was not implemented. The evidence is not yet adequate to characterize the extent to which current practices and equipment (e.g., use of the T-11 and updated procedures (DA 2018) have reduced risks or changed the injury distributions (i.e., most common injury types and body regions affected).

Injury types and body regions injured appear to vary depending on the paratrooper population. Lower extremity and ankle injuries appear to be most common among airborne trainees, while operational paratroopers more frequently experience acute back and spine and head and neck injuries. Data is limited to the acute trauma injuries that occur at the time of jumps. While this makes sense given the tremendous force on the body during landing impact, data does not reflect injuries associated with overall cumulative experience of repeated jump exposures over time or the combination of jumping exposures with paratroopers' other military occupational exposures.

Specific issues for future study.

- *The injury risk experienced by military parachuting occupations compared to that of other military occupations is unknown*. The literature provides injury rates for paratroopers (injuries/1000 jumps) that cannot be compared to injury rates attributed to other military activities since the units of measure are based on soldiers' jump exposures. Though it is plausible that paratroopers experience a higher rate of injuries than military cohorts, who do not have jump-related duties, the unique risk to the paratrooper population has yet to be quantified.

- *Published paratrooper injury rates describe only acute trauma injuries, and even acute injuries were not consistently defined or categorized.* The paratrooper literature has understandably focused on the acute trauma (ACT) injuries directly caused by jumps from aircraft. However, as several studies have pointed out, there were inconsistencies as to what "injuries" were included and their severity. Also, there were notable variations in how injured body regions and injury types were portrayed. These variations precluded a quantifiable analysis of previously reported results. Furthermore, because the design previous studies was limited to the immediate acute traumatic injuries, there is currently no evidence available to quantify the cumulative microtraumatic (CMT) injuries experiences by paratroopers. The CMT injuries could be associated by the repeated jumping exposures of this population or the combination of their jump exposures with other required physical activities (e.g., the load carriage and foot marching required after jumps). To this extent, injury estimates described by existing literature underestimates the risk of *all* injuries (ACT and CMT) in paratrooper populations. In addition, the plausibility of injury- related MSK long term effects and chronic conditions attributed to parachuting related exposures cannot be characterized with the current evidence.

- *Medical surveillance of paratroopers may not be a practical solution*. Prior studies primarily relied on field observations and medical data collection. Several studies recommended a medical surveillance program to standardize the routine collection and analyses of paratroopers' specific jump-related injuries. While there is now a well-established Army medical surveillance system to identify individuals' injury diagnoses, the medical record data do not reliably provide causal information. Specifically, the medical "external cause codes" available to providers to assign when diagnosing injuries are used in less than 10 percent of cases, even less for those treated in outpatient visits (Rucsio 2010). The difficulties of attributing injuries to specific causes may be better addressed through episodic investigations of populations known to conduct parachuting activities. Details regarding specific jump exposures could be obtained from populations through the use of self-report surveys.

- *Injury rates vary for unique populations—U.S. trainees may have lowest risks*. Of the acute injuries tied to specific jump exposures, evidence shows that trainees experience lower injury rates than those who become operational paratroopers. Specifically, the lowest rates reported (U.S. Airborne trainees, approximately 6 acute injuries per 1000 jumps) were more than 50% less than those for U.S. operational paratroopers (approximately 15 acute injuries per 1000 jumps. This difference is despite an assumed higher jump exposure among trainees (five jumps in the last week of a three week program) compared to operational paratrooper who may jump as few as four times a year. Though operational paratroopers may have less jumps or a less intense annual exposure period, the frequency or number of annual jumps is not centrally tracked in an Army-wide system, so their exposures are unknown. However, trainees are focused exclusively on learning proper jump technique and receive continuous oversight in a safety-oriented program. It is hypothesized that higher injury rates in operational units could be due to the combination of numerous extrinsic risk factors (e.g., tactical environments, combat gear, low light), as well as fatigue and distraction from proper jump procedures due to the concurrent management of other hazards.

- *Characterizing paratrooper injuries by a single injury rate obscures variations among populations and risk factors*. A commonly cited paratrooper rate of 6 acute injuries per 1000 jumps may be a reasonable estimate for U.S. Airborne trainees, but is likely too low an estimate for operational paratroopers.

  - Risk ranges may be most appropriate to characterize general paratrooper injury rates, especially for operational units. A U.S. operational paratrooper acute injury rate can be described as between 5 to 50 injuries per 1000 jumps, depending on risk factors, with an average rate of approximately 15 injuries per 1000 jumps.

  - Rates can be expected to be at the lowest when the least number of risk factors are present and highest when multiple factors are present (such as, wearing combat gear, night time or low-light conditions, and not adhering to or being able to adhere to proper PLF procedures).

- *The nature of injuries and body regions injured may differ among populations.* Evidence suggests acute injury patterns of trainees may be different than those experienced by operational paratrooper. This can be better determined by standardizing body region and injury type grouping in future studies (APHC, 2017). Injury prevention strategies may need to be tailored to the injuries most prevalent within a specific population.

  - The lower extremity region is frequently injured among paratroopers. Within this region the ankle the most commonly injured specific anatomical site, though ankle injuries have been more prominently identified in studies of trainees. The ankle may not be the most commonly injured site in operational paratroopers. Evidence also indicates that among ankle injuries, sprains and soft tissue damage are more common than fractures. Other less frequent lower extremity injuries include strains/tears to knee ligaments and fractures to the foot, toe, and lower leg.

  - Head, neck and back or spine injuries appear to be more common among operational paratroopers. Of primary concern are “closed head wounds,” which include concussions and TBI. Head and neck injuries are thought to result from backward falls on landing or the jarring impact when head whips back during the PLF forward tuck. Specific assessment of and associated costs may help clarify priorities, causes, and identify potential new reduction strategies. Data was lacking regarding the severity of back, neck, and spine injuries.

  - Upper extremity injuries among paratroopers are primarily to the shoulder, and include dislocations and fractures. Though overall less commonly reported than lower extremity injuries, Australian studies found these to be leading paratrooper injuries and two U.S. studies of the new T-11 parachute found that shoulder injury rates doubled compared to T-10 parachute rates. This evidence suggests shoulder injuries may be associated with unique equipment or procedural protocols. Data is inconsistent regarding the severity of shoulder injuries compared to those of the lower extremities.

- *In operational settings certain risk factors may be unavoidable, but PLF compliance could be assessed.*

  - Evidence suggests that “improper landing” and not adhering to proper PLF procedure is the most significant factor to increase the risk in operational settings. Data does not provide adequate evidence as to the reasons for improper landing, which may be attributed to many factors. These factors include wearing combat gear and jumping in tactical and low light settings, but could also be due to the lack of experience/training and/or lack of procedure oversight/enforcement. Current Army doctrine emphasizing training requirements, procedures with the T-11, and common errors associated with the PLF (Appendix C) may help to reduce injuries.

  - There is strong evidence that wearing combat gear/operating in a tactical setting (especially when landing area is uneven) and/or jumping in low light or night time settings are significant factors that will increase injury risk during a jump.

  - Evidence is limited as to the degree risk contributed by other external factors (i.e., wind speed, type of plane, and jump location (side or rear); though, it appears these factors especially in conjunction with other factors can impact risk.

  - Evidence is inadequate to indicate risk attributed to demographic factors (i.e., gender or age).

- *Scientifically proving effectiveness of an injury intervention does not equate to use.* The scientific evidence published since 1990 provides data for two equipment items considered as potential paratrooper injury interventions.

  - The PAB was repeatedly found to be effective at reducing overall injury rates due to reduction of ankle-related injuries. Despite this strong evidence, the PAB was not adopted by the United States or any international paratrooper community for reasons cited as discomfort and impracticality. The cultural acceptance of an intervention may be a first priority of consideration when identifying future studies.

  - The U.S. Army has implemented the use of the new parachute design (T-11) replacing the previous model (T-10) due to various operational benefits, which included a slower rate of descent and reduced oscillation. The decision to implement the T-11 was not based on injury reduction; though, data suggests this is one of its benefits.

Recommendations.

- *Compare the risk of injuries between paratroopers and other military populations*. A future investigation could identify differences in injury rates, types and body regions, and cost (as a surrogate for severity), between a defined Active Army paratrooper population and a comparison cohort.

- *Use a standardized injury definition, body region categories, and injury type groups in future assessments of paratroopers' injuries.* For example, the use of the definition of injuries as defined by the APHC, applied to International Classification of Disease (ICD) diagnosis codes in medical records, could be used to assess all mechanical injuries in standardized body region, anatomical site, and type of injury categories (APHC 2017).

- *Evaluate risk of both CMT injuries as well as ACT injuries*. The use of medical records can be used to identify and characterize both ACT musculoskeletal (MSK) injuries and CMT MSK injuries in paratroopers and comparison populations.

- *Use survey data to assess causes of injuries*. An investigation between paratroopers and comparison populations could use survey data to identify jump exposures associated with injuries.

- *Identify specific types of body region injuries to suggest equipment and/or procedural changes to reduce injuries.* For example, a head or neck protection device has previously been suggested to reduce neck injuries. Prior any field study of an intervention, determine practicality and cultural acceptance of any item or procedure.

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APPENDIX A

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APPENDIX B

Military Parachuting Injury Literature

This appendix contains a reference table that summarizes information from the identified military paratrooper injury literature (in chronological order).

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Lillywhite 1991	*Operational paratroopers:* − Five UK Airborne Brigades − prior 1989 − 34,236 static line jumps − Day, night, most with combat equipment	STUDY: Field collect by medical party in DZ	'all' jumps including balloon and helicopter = 11/1000 jumps (1.1%) [379 injuries/ 34,236 jumps] 14.6/1000 (1.46%) for aircraft (C-30) – excluding balloon (4.0%) and helicopter (0.04%) Day 1.07% vs Night 1.37%	"*caused during parachuting and attended to by medical party in the DZ*"	↑ Weight equipment (combat)* ↑ Night ↑ Number people exiting (i.e., >65 greatest risk, then 64 – 23, and least risk 1-22) ↑ Wind speed/direction * Most of those injured (88%) with equipment	Indicates higher than expected rates compared to those previously reported
Farrow 1992	*Operational paratroopers:* − Australian Parachute Battalion − 1987-88 − 8,886 static jumps from C-7, C-130 aircraft. Mix conditions- Equipment, no equipment, simultaneous exits	STUDY: Prospective field medical report collection	7.1/1000 (0.71%) Combat equipment = 13.7/1000 (1.4%) Tactical simultaneous doors- 16.6/1000 (1.7%)	"*…recorded only if severe enough to require evacuation from DZ*" "*…this study was to gain insight into injuries that would prevent a soldier from 'carrying on.'*" Classifies as Minor, Moderate, Severe - Severe - Shoulder (11%) Ankle fracture (5%) Minor - Ankle sprain (11%)	↑ Improper landing (87% injuries (n=63) on landing)* ↑ Weight equipment (combat) ↑ Simultaneous exits both sides aircraft ↑ Wind speed(winds both slower than 5 knots and greater than 10 knots ↑severity of injuries) ↑ Exercise (tactical) descents ↓ Design (maneuverability) ↓ Civilian 1-3/1000, no equipment, "safer overall," but more likely to be severe	"*The definition of injury has varied in all published reports of parachute accidents.*" "*…PLF [1943]… instead of forward roll reduced ankle fracture rate by 50%.*" Concludes most injuries are on landing.

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
				Lower extremities mostly "minor" while upper extremities mostly "severe"		
Kragh 1996	*Operational paratroopers:* − 556 Rangers, U.S. Army 3rd Ranger Battalion; 75th Ranger Regiment − Unspecified dates – (presumed early 1990s). − 7,880 static line jumps. Day, night, and different landing points	STUDY: Field medical, record review	Overall 22/1000 jumps (2.2%) 4.7% for dirt landing strips; airport 2.3%; 1.6% fields, 0% water 2.7% Night vs 1.4% day	"…*acute anatomic lesion producing duty restriction*" Three levels severity - Mild=<72 hours physical activity restriction; Moderate= >72 hrs restriction; Severe= >24 hrs complete work loss (e.g., hospitalized) Lower extremities >50% injuries, i.e., - Knee (collateral ligament, anterior cruciate ligament (ACL) sprain; meniscus tear) - Ankle sprains Back/spine ~15% (i.e., thoracolumbar strains/sprains)	↑ Night (2.5 greater injury risk) ↑ Dirt landing strip >Airport> field	Static line jumps per ranger = 7-200; mean = 34; average rank = E5; average military service = 4.4 years
Craig 1997	*Operational paratroopers:* − Paratroopers at Ft. Bragg seen in ER − May 1993-Dec 1994 200,571 jumps.	STUDY: ER records analyses; Monthly airdrop summary reports	8/1000 (0.8%) Monthly range varied a lot: 5.4% – 12.9% 4.7 injuries/100 Soldiers per year-	INJURY = required ER visit; "…*determined by ER staff to have occurred during airborne operation.*" - Lower extremities, 27% - Back/neck, 19% - Closed head, 18% Primarily sprains,45% - ankle, back, neck	↑ <30 yr (18-29) have 50% more risk (*possibly due to experience*) ↑ >30-yr femur and pelvic fx (*possibly due to aging bone structure*)	"*…plan for ~ 10 acute traumas/1000 jump… with variation of 50% depending wind, weather, experience*)…." "*Incidence low at Ft Bragg due to safety, quality of training*"

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
			5.8 injuries/100 Soldiers (18-29 yr)/ per year vs 2.7 injuries/100 Soldiers (30+ yr)/ per year	Fractures - fibular, foot, tibiofibular, tibia, ankle		Recommends - - neck exercises (strength) for head tuck (since Kevlar helmet is 3-4.25 lbs) - "neck guard" like football players
Craig 1999	*Operational paratroopers:* − Operation Royal Dragon, U.S. and U.K. training exercise − 1996 − 4,754 jumps (U.S. = 3,066; U.K. 1,688) 137 injuries (U.S. 68; U.K. = 49)	STUDY: Casualty collection points (field medical)	Overall "*2.5% personnel incidence*" U.S. =22/1000 jumps (2.2%) versus U.K.= 29/1000 (2.9%) 15 hospital (U.S. 8, U.K. 7)	'evaluated by field collection' U.S results - Lower extremities,* 38% Back, 16% (sprain/strain) Closed Head,10% Neck, 7% *did not specify ankle versus knee injuries 'Severe/more serious disabling injuries' included strain/sprain as well as fractures	"*The 2.5% personnel incidence was 0.8 higher than previous at Ft Bragg, however this was a mass tactical, combat equipment assault; conducted at night in inclement weather*." Weather = rain and fog, wind up to 8 knots.	Observed 2.5% "*exactly as predicted by planners*" U.S. vs U.K. not statistically different injury rates but.. " UK soldiers sustained more disabling injuries (fracture (fx), sprain, strain lower extremity) than U.S. (16/1000 vs 9/1000)
Ekeland 1997	*Trainees:* − Norwegian paratrooper trainees and Reserves − 1970-1988 − 2031 jumps trainees, 2468 jumps Reserves static and some free fall; 25-30 jumps in basic	STUDY: Field collection, medical	11.3/100 jumps (1.1%) 19.7/1000 jumps for basic 4.5/1000 for post – basic training exercises	'sought medical consult for, whether or not sick leave or seen several days after injury' - Lower extremity, 80% (ankle 36%, knee 18%, lower leg11% foot 11%) - Spine 11%	↑ Improper landing technique (71% injuries) ↑ Trainees* * less experience possibly reason; injury risk found to be highest in earlier training jumps Age does not appear to be a risk factor	Most injuries on landing (possibly associated with wind gusts, rough terrain, equipment issues) "*11/1000 is relatively low injury rate*" (NOTE: this conclusion does not align with other found data)
Amoroso 1998	*Trainees:*	STUDY:	10.8/1000 (no brace) vs	'..*any MSK or traumatic condition occurring from*	↑ No ankle brace	Lower extremities, 80% primary

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
	− 745 U.S. Airborne School, (369 brace wearers, 376 no brace) − Early-mid 1990s − 7,674 jumps − each student 5 jumps – single, mass, night equipment	Randomized intervention trial (PAB); field collection-medical	9.4/1000 (brace) Lower extremity (no brace) =8.6/1000 (0.9%) vs 7.2/1000 (brace)	*aircraft exit to DZ march off that results in inability to clear DZ/ER visit, or Dx at troop medical clinic.*' Separate criteria for ankle inversion sprain, syndesmosis sprains, leg strains, knee sprains, etc.		injuries; most to ankle (30-60%) = sprain, strain, fractures
Bar-Dayan 1998	*Trainees:* − Israeli Parachuting Training Center; trainees and refresher training − Mid 1990s − 43,542 static line jumps	STUDY: Accident reports and flight manifests; hospital consults	9/1000 = 0.9% "*rate of minor injuries 0.68%"*	"*casualty that prevented further jumps for at least 2 days after injury*" -Minor injury (contusion, sprain) most common (68%) such as - Ankle sprain, 25% Ankle contusion, 07% Other contusions,32% - Major injury (fx, dislcn, head trauma) = 21% Head trauma 0.07 Ankle fracture 0.07 Tibial fracture 0.07	↑ Night '*..head trauma due to backwards fall on landing; …more prominent at night'*	"*The overall injury rate in this study was 9 per 1,000 plane jumps, compared with injury rates of 3.1 to 14 per 1,000jumps published elsewhere. Differences in the definition of parachuting injuries are probably one of the most important factors making comparison between injury rates of parachuting centers difficult and inaccurate."* "*risks of parachuting relatively low, injury*

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
						rate estimated to be 0.3 to 1.4%" "*majority are lower extremities [due to impact absorbed during landing] and vertebral ..*" *and are "attributed to poor parachuting or landing techniques"*
Bricknell 1999	*Operational paratroopers:* *AND Trainees:* − Military operational, trainees, plus Civilian (international) − Data published 1940-1995 − Focused on static line jumps; multiple variable (day, night, equipment, landing)	REVIEW: Literature review	Mean = 5.6/1000 (Range =0.9-22/1000 jumps) STD 3.8, CI 6.8-4.9) Civilian rate =4.4 All scenarios , including from balloon = 5.6/1000 (mean), range 0.9/1000-22/1000; Aircraft, Daytime, no equipment = 1.8/1000	INJURY = *as reported in other studies* Head & Neck= 6.4 (closed/concussion) Shoulder= 5.3 (dislocations (dslc)) Arm = 1.6 Chest/rib/abd =4.2 Back =40 (contus, fx, sprain) Leg=38 (ankle spr, fx, dslc; knee sprain; tibia/fibia fx	↑ Windspeed ↑ Multiple parachutists ↑ Night ↑ Hard/uneven terrain ↑ Height and Weight ↑ Inexperience ↕ Design of parachute ↓ Balloon descent vs aircraft	Describes PLF technique and "classic" injuries– · Concussions when head whipped back · Shldr fx/dslc from PLF elbow out · Tricept/bicept brach from arm entrapment on static line on exit of aircraft · Acro-Clav joint dslc from landing on shoulder · Tib/Fib fx/strain from sideway PLF strain on fib · Compressed vertebrae from

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
			Aircraft, Daytime, with equipment = 8.5/1000 Aircraft, Nighttime, with equipment = 10.1/1000			backwards land lean · Knee ligament injuries from excessive abduction of lower leg somersaulting against rig lines · Fx of posterior tip of tibia from landing w toes pointed down *Recommends*: Standardized medical surveillance, injury types, body regions, risk factors, demographics
Schumacher 2000	*Operational paratroopers:* − U.S. Airborne Ranger Battalion, cohorts w/o PAB (1994- 1996); 7,857 jumps) versus vs w PAB (1996-1997; 5,928 jumps Jumps mostly at night, from C-141/C-130, with T10-C, static line, onto field/airfields , moderate winds, with equipment’	STUDY: Medical assess-ment of duty-restricting injury	17/1000 (1.7%) w/o PAB vs 13/1000 (1.3%) w PAB RR 1.25 210 injuries total (132/78)	*’duty limiting injury per sick call or ER visit’* Ankle 27% Back, 21% Knee, 20% Head, <2% Ankle injuries: 4.5 vs 1.52/1000 w PAB - Ankle - Back - Knee - Foot	↑ No ankle brace *Without PAB* Lower extremities >75% (ankle, knee, foot, leg, hip)	“*Ankle injuries most common in Civilian and military, accounting for 15-60% all injuries*” ‘316 day lost duty/1000 jumps from ankle injuries’ PAB reduce eversion and inversion ankle injuries – most common ankle injury from parachuting

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
						PAB does not show increase foot, leg, knee, back)
[Knapik 2003]	*Operational paratroopers AND Trainees:* − Military operations, or training − Data published 1944-1997 Mostly static line jumps (vs free fall, 2 of 18 studies)	REVIEW: Literature review	(6/1000, per Bricknell 1999)	*as reported in various publications* NOTE: Injury types and body regions not described in this review	↑ Aircraft vs Balloon/helicopter ↑ Windspeed >10-15 pmh ↑ Night ↑ Weight equipment (combat) ↑ Hard/uneven terrain ↑ Female gender (fx) ↑ No ankle brace <u>Limited evidence:</u> ↑ Multiple paratroopers ↑ Winds from rear of aircraft ↑ Simultaneous exits on both sides aircraft ↑ Smaller parachute canopies ↑ Higher ambient air temperatures ↑ Airborne refresh vs intro course Poor evidence – height/weight of paratrooper	Good description of U.S. Airborne jump process and roles Inter study variables: - different (injury) case definitions, - data collection methods, - type of Soldiers and missions - national affiliations

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Schmidt 2005	*Trainees:* - U.S. Airborne School, 939 parachuting hospitalizations - 1985-2002 - Comparison of injury rates during PAB use and no PAB use each student 5 jumps – single, mass, night equipment jumps	STUDY: Retro-spective review of hospital medical records database (*not field*)	All injuries: 5.4/1000 pre PAB 2.7/1000 pre PAB 3.6/1000 pre PAB	Identified based on medical records review of selected ICD codes *with parachuting external cause code* *Ankle versus non-ankle injuries:* 63% for ankle injury ankle injury rate: 3.5 pre PAB to 1.5 with PAB 2.5 post PAB OR pre: PAB 2.4:1 With PAB 1:1 OR post: PAB 1.7:1	↑ No ankle brace	Use of PAB: Jan1985-Spt93-pre: PAB Oct1993-Dec93-EXC Jan1994-Spt2000-PAB Oct 2000-Dec02-post:PAB '*Occurrence of other traumatic injuries not increased with use of PAB*' 'Ratio of $ 30,000/yr for braces compared to hospital costs ($835,000/yr) = 1:29'
Hay 2006	*Operational paratroopers:* - Australian 3rd Royal Battalion - 2004 - 1,985 static line jumps - jumps without equipment, with equipment, and tactical with equipment	STUDY: Retro-spective review of manifest records and review of medical record	15.3/1000 overall: 10.3 no equipment, 11.2 with equipment, 32.6 tactical with combat equipment	Like Farrow 1992: 'recorded only if severe enough to require evacuation from DZ' Back, 29% Shoulder, 19% Head/neck, 9.5%	↑ Weight equipment (combat)	Recommends need to change reporting culture - encourage soldiers to report sooner to minimize "broken" soldiers

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Hughes 2008	*Operational paratroopers:* - Australian 4th Royal Battalion. 254 paratroopers - 2004-2005 554 static line jumps	STUDY: Field and medical record review	"*casualty rate*" = 5.1% (51/1000) 28 injuries/554 jumps 10 personnel required hospital = 2.6%	Injury definition not clear Injuries two types for mission planning: severe require emergency evacuation /treatment and "less severe' with minor restriction of performance Back injuries, 75% Shoulder, 25%	Discussed: ↑ Height and Weight (equipment?) ↑ No ankle brace ↑ Uneven terrain "*most dangerous component [of parachuting] is the landing" PLF involves landing with feet and knees together, …. On impact, paratrooper turns on side into direction of landing and rolls onto lateral aspect of leg and thigh to disperse energy to a wider area – impact 4.6 – 6.7 m/s (greater with horizontal wind speed*) .."	"*Direct comparison of injury rates between studies is complicated by lack of a standardized definition of "injury" within published reports..*" "*Military static line parachuting allows insertion of many troops in area within short time*"
Knapik 2008	*Trainees:* - 596 U.S. Airborne trainees - 2005-2006 - 102,784 jumps - each student 5 jumps (T10)- single, mass, night, equipment	STUDY: Field collection; medics, other medical	5.8/1000 5.2 with PAB 6.1 no PAB	INJURY = *not clear* Anatomic regions Ankle = 37% (sprains) Shin = 8.4% Ft/toe = 6.2% Head = 17% Shoulder = 6.9% % injury types: Sprain = 33% Fx = 25% Concussion = 16%	↑ No ankle brace	'*21-24/1000 injuries in 1940's when parachuting techniques developed as parachute design and techniques improved rates declined to 6/1000*' '*Ankle accounts for 21-43% of all injuries*'

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Deaton 2010	*Operational paratroopers: (deployed):* - U.S. Marines unit Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF) - 2008-9 - 972 static line jumps Mixed senarios and equipment (majority C-130, some helicopter, MV Osprey; day, night, equipment and no equipment)	STUDY: Medical evaluation	8.2/1000 jumps (0.8%) 2.1 Major (0.2%) 6.2 Minor (0.6%)	"*….presented to military surgeon… related to airborne operation regardless of .light or limited duty status.*" Major = evacuation required Lower extremities, >60% Upper leg/knee 50% Ankle 12% Head/neck 37%	↓ Rear tailgate exit ↑ Night/low light ↑ Inexperience/poor PLF ↑ Weight equipment (combat) ↓ Design=Maneuverable ↕ Windspeed = Age 20-29 years	Describes rates of 3-24/1000,' most not maneuverable which would expected to be lower "*All services should consider a centralized data repository that tracks comprehensive injury profiles – not just significant mishaps or deaths …[This..] would allow medical planners best to place limited assets for combat airborne ops; Services should place emphasis on finding a common, steerable, static line parachute in hopes of decreasing overall injury and attrition rates*"

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Knapik 2010	*Operational paratroopers AND Trainees:* - Military paratroopers/ trainees, with and with w/o ankle braces (PAB) Publication of PAB to 2010	REVIEW: Systematic Literature review (parachute ankle brace)	Ankle only = 2.6/1000 trainees; 4.5/1000 operational PAB= ~ '50% reduction ankle injury'	As reported in publications (focus is on ankle injury as described as site w most injuries) <u>Ankle only =</u> Ankle 21-43% injuries Ankle sprain 9-33% Ankle fractures 7-23%	↑ No ankle brace	Calculates and estimated annual PAB cost savings for: Airborne students = **$ 0.6 million/year** Operational paratroopers= **$ 1.1-3.4 million/year** Assumptions for cost calculation: "For every 4 ankle injuries, assume 3 = sprains, 1 = fx.… 8 follow-up visits /sprain and 21 follow up visits /fx.."
Luippold 2011	*Trainees:* - Airborne trainees - Student rosters for 1998- 2006 - 5 jumps/student single, mass, night, equipment	STUDY: Medical record database compared to Rosters (no field)	Describes "40% reduction ankle injuries with PAB"	Injury definition is not clear – describes use of 'ICD-9 acute traumatic codes plus others' Ankle injuries 29% all injuries	↑ No ankle brace	Intended to address 'anecdotal reports [that] continue to suggest increase of risk of other types of injury, and cost of PAB used to justify discontinuing its use'

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
Knapik 2011a	*Operational paratroopers* - 82nd Airborne infantry - 20,031 jumps - T-10D	STUDY: Field collection; Medical evaluation	10.5/1000 (1.1%) 242 injured Soldiers/20,031 jumps	Determined by field medical – physician confirmed Body Regions (%) Head = 34 Back = 11 UpperArm = 7 Shldr = 5 Knee = 6 Ankle = 18 Injury types (%): Cncss/closed hd 31 Fx = 15 Sprain = 13 Contusion 12	Ground Impact/PLF (75%) Static line (11%) Other = tree landing+ entanglement, landing on equipment, dragged on ground, etc… ↑ C17 & C130 (jumps are low ~ 800ft) *Notable univariate* risk factors associated with ↑ injury incidence- Night time, combat loads, higher wind speeds, higher dry bulb temp, higher humidity, C17 Globemaster/C130 Hercules (vs other aircraft), exits through aircraft side doors (vs tailgates), and entanglements. *Multivariate risk factors of note* night, combat loads, higher wind speeds, higher dry bulb temp and entanglements.	Good PLF description
Knapik 2011b	*Trainees:* - Airborne trainees - March – Sept 2010 - 30,755 jumps; (T10 vs T11) - each student 5 jumps – single, mass, night equipment, jumps	STUDY: Field collection	2.5/1000 (0.2%) 76 Injuries/30,755 T10 = 2.9/1000 jumps 61 injuries/ 21,404	Field medical – physician confirmed Body Regions (%) **all /T10/T11** Ankle = 32 / 34 / 20 Head = 15 / 15 / 13 Shin = 9.2 / 6.6 / 20 Shldr = 9.2 / 6.6 / 20 Ft/toe = 7.9 / 10 / 0 Back = 5.3 / 3.3	↑ T10 parachute	'T11 has 40% lower injury incident rate during daytime jumps w/or loads....' Other studies of T11 needed – especially with operational units, at night, with combat loads

Publication	Population/Scenario	Design	Injury Rate	Injury definition, types	Risk factors	NOTES
			T-11 = 1.6/1000 jumps (15 injuries/9,351 jumps) Risk ratio T10/T11=51.8, 95% CI 1.01 – 3.12, *P* 0.04	Injury types (%): Fx = 30 / 28 / 40 Sprain = 13 / 15 / 17 Cncuss = 13 / 13 / 13		
Knapik 2014	*Operational paratroopers* - 82nd Airborne unit and 18th Air Support Ops - 2010-2013 - 131,747 jumps - T-10D vs T11	STUDY: Field collection; Medical eval and record review	8.4/1000 1101 injuries/131,747 jumps T-10 9.1/1000 T11 5.5/1000 Odds ratio (T-10/T-11): 1.72, 95% 95%CI 1.45 – 2.08, *P* 0.01	"*any physical damage to the body, seen by medic or PA in the drop zone from time on aircraft to time removing harness*" Body regions (%): **T10/ T11** Head = 38 / 29 Ankle = 15 / 15 Low Back = 12 / 7 Knee = 6 / 7 Shldr = 4 / 8 Injury types (%): **T10/ T11** Head trauma 35 / 29 Fx = 14 / 10 Sprain = 14 / 16 Contusion 12 / 14	↑ T10 parachute ↑ Night ↑ Equipment (combat load) ↓ Rotary wing Possible ↑ entanglement injury w T11 but percent entangle injuries extremely small, primary associated w exit vents	Reduction injuries with T11: Hypothesis Slower descent velocity and reduced oscillation 5-6 m/s velocity slightly slower w T11 Indicates most injuries on ground impact) 88%) Indicates that 95% injuries were found in AHLTA med records (only 5% not)

APPENDIX C

Static Line Parachuting and the Parachute Landing Fall

Information extracted from:
Training Circular 3-21.220, Static Line Parachuting Techniques and Training, October 2018 (DA 2018)

Para 3-85. …. To lessen the possibility of injuries, the jumper is trained to absorb the impact of landing by executing a proper PLF. To do this, the following five fleshy portions of the body must contact the ground in sequence:

- Balls of feet
- Calf
- Thigh
- Buttocks
- Pull-up muscle

Para 3-86. The three basic PLFs are:

- Side (right or left)
- Front (right or left)
- Rear (right or left)

Para 3-87. The direction of the wind drift dictates the type of fall the jumper will make. The jumper judges the direction of drift by looking at the ground before assuming the landing attitude. The jumper prepares to make the appropriate PLF after determining the direction of the wind and the type of fall."

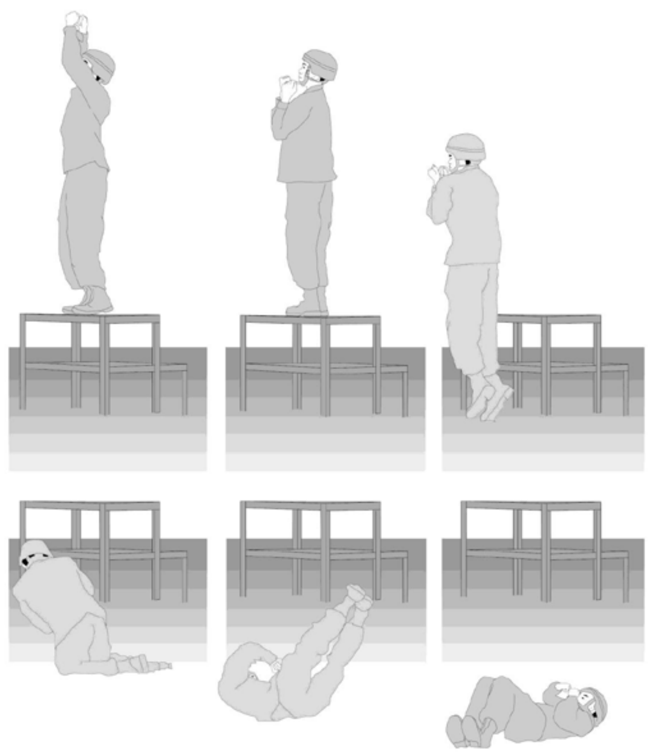

Figure C-1. (4-1, TC 3-2.220) Parachute Landing Fall Sequence

Table C-1. (Table 4-1, TC 3-2.220) Common Parachute Landing Fall Errors

ERROR	*CAUSE*	*CORRECTION*
Feet apart	Anticipation of landing.	Keep moderate muscle tension in the legs. Keep feet and knees together.
Drawing the legs up under the buttocks	Anticipation of landing. Relaxing the knees. Exaggeration of the bend in the knees. Pulling feet up upon landing.	Keep moderate muscle tension in legs. Maintain a proper prepare-to-land attitude, naturally exposing the balls of the feet to the ground.
Missing the second (calf) and third (thigh) points of contact	Feet and knees apart. Straightening the legs. Failure to shift the knees.	Bend the knees slightly. Keep feet and knees together. Shift and bend the knees throughout the fall.
Knees into the ground	Hesitation upon landing. Pushing knees forward toward ground. Excessive bend in knees. Turning the feet toward the direction of drift.	Do not hesitate upon landing. Shift knees to the side. Keep moderate muscle tension in legs. Maintain the proper prepare-to-land attitude.
Elbows hit the ground	Leaning forward toward ground. Failure to rotate upper body away from ground. Breaking fall with elbows.	Rotate upper body away from the ground with elbows up and in front of face.
Head strikes the ground	Relaxing the neck. Arching the back during the prepare-to-land attitude. Rotating the upper body into the ground. Missing the points of contact.	Keep chin on chest. Tense neck muscles throughout the PLF. Assume proper prepare-to-land attitude. Rotate upper body away from the ground.

PARACHUTE LANDING FALLS AND MALFUNCTIONS

Para 8-40. Parachute landing falls must be performed by all manifested jumpers. Each jumper must perform one satisfactory PLF in each of the four directions:

- Left side
- Right side
- Front (left or right)
- Rear (left or right)

Note. In order to prevent jumpers from colliding or landing on each other, [jump masters] will dictate which front and rear PLF jumpers will execute during PLF training in order to maintain control, and ensure all jumpers on the platform are falling in the same direction.

Note. The first commander (O-5) in the chain of command can extend or waive the individual jumper's requirement for executing a parachute jump from 60 days up to 90 days after successful completion of Basic Airborne Refresher Training. Unit commanders take into consideration each individual's experience level with the T-11 and MC-6 and their ability to retain the crucial information they receive during Basic Airborne Refresher Training. The 90-day waiver is submitted on a memorandum for record and placed with the individual's jump log."

[Extracted from Appendix A TC 3-2.220—Basic Airborne Refresher Training]

"Basic Airborne Refresher Training is a requirement for all personnel who have not jumped the T-11 ATPS or MC-6 series parachute within a six-month period (180 days) or for personnel who have not conducted an Airborne operation with either parachute system. Any current and qualified jumpmaster can conduct Basic Airborne Refresher Training at the unit level with the lieutenant colonel (O-5) commander's approval.

Notes. T-11 and MC-6 transition training formally conducted for personnel who have not executed a jump with the T-11 ATPS or the MC-6 series parachute is no longer a separate requirement from Basic Airborne Refresher Training.
All jumpers who have not jumped the T-11 ATPS and MC-6 series parachutes within the last 6 months (180 days) will meet the minimum ….The length of training should not be not dependent on the jumper's experience or proficiency but on the minimum requirements …The training is instructed and documented by a current and qualified jump master.

WARNING
It is highly recommended that unit leadership take a deliberate approach to training individuals who have never executed a T-11 ATPS jump and develop a progression plan for individuals who have less than 10 jumps with the T-11 ATPS. These jumpers are statistically at the highest risk for a parachute incident."